THE EFFECT OF FOULING ON FUEL CONSUMPTION

by

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Comment, sometimes embarrassing, is often made on the differing furnace fuel consumptions incurred by similar ships of the same class operating under reputedly similar conditions. Variations are attributed to station keeping, the height of the barometer, and many other variables such as the state of health of the Chief Petty Officer Stoker Mechanic responsible for dipping the tanks.

The result is reflected in annual fuel returns, on Forms S.231, and, more important, in the widely differing figures given for endurance in certain official publications.

An instance of this in the 8th Destroyer Flotilla (*Cossack* Class) in the Far Eastern Fleet led to interesting results. Fuel consumptions of the five ships in the flotilla had varied widely ; it was therefore decided to carry out consumption trials while on a passage from Kure to Hong Kong in September, 1948.

The Comparative Consumption Trial. Ships were ordered to form line abreast and take station on *Cossack* (in the centre) at 14 knots. Ships were then ordered to revert to " economical steaming ". This was the flotilla executive order permitting the stopping of certain auxiliaries (such as the main feed pump) which are normally required during exercises, and thus assuming the most economical conditions possible, at some loss of manoeuvrability (which can be accepted on passage but not during exercise periods).

After two hours it was assumed that all ships had achieved steady r.p.m., and the flotilla was then instructed to start a twelve-hour consumption trial through the night *maintaining these steady r.p.m. irrespective of station keeping.*

Speculation was rife as to whether all ships would still be mutually in sight at dawn. At the end of the twelve hours, however, only three miles separated the leading and rearmost ships (*i.e.*, three miles' difference in 168 miles). But some consternation was caused when the fuel consumptions were signalled, since the heaviest consumption was 70% greater than the lightest over the twelve hours' period.

All ships then worked up to full power, having connected the second boiler, and took spot readings over a quarter of an hour. (*Constance* and *Concord* continued for their periodical two-hour full power trial.) Fuel consumptions were not so remarkably different as at cruising speeds.

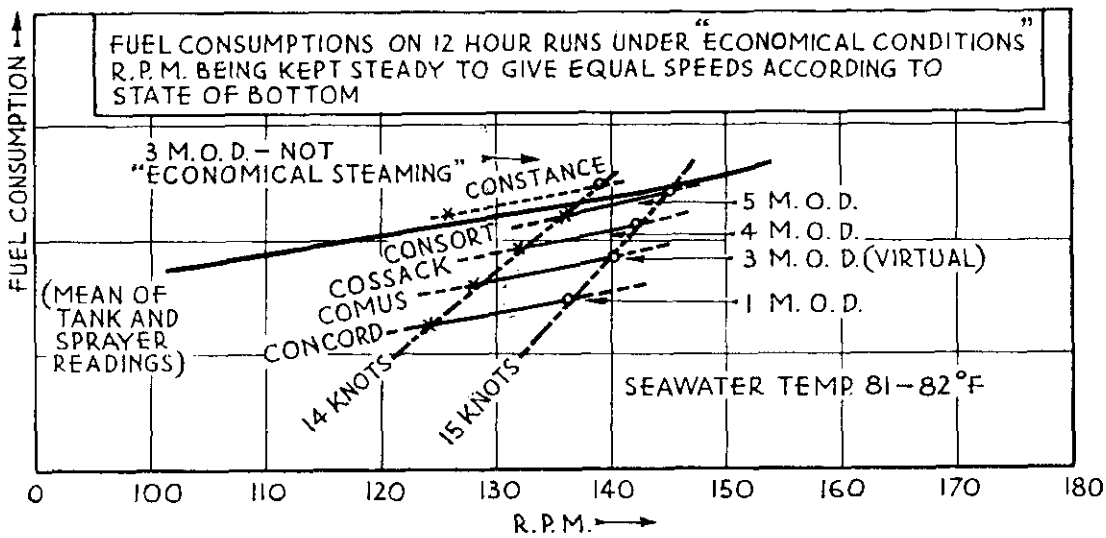

FIG. 1.—(ACTUAL FUEL CONSUMPTION FIGURES ARE NOT GIVEN FOR SECURITY REASONS)

The following night a repeat of the first trial was carried out, but at 15 knots : this time, however, the flotilla had to be worked in two groups of three and two since *Constance* and *Concord* had gone ahead ; again the fuel consumptions varied 70% over the twelve hours.

Fuel consumptions were deduced from the mean of tank dips (every watch) and of sprayer outputs, the two agreeing remarkably closely. The sea was calm and allowed accurate dips. In fact, the conditions for comparative trials were ideal.

The machinery used during " economical steaming " was very nearly the same in all ships except in *Constance* who, due to misunderstanding, was still running a main feed pump, two boiler room fans on the single boiler and with evaporators on live steam instead of closed exhaust, this being the machinery usually run under normal steaming (exercise) conditions. Displacements of all ships were approximately the same.

Analysis of the Trial. The results of these trials are shown in the following figures. Fig. 1 indicates the consumptions in the nominal 14-knot and 15-knot trials on a base of r.p.m. It was then evident that the wide differences in consumption bore a relation to " time out of dock " : those for *Concord* (one month), *Cossack* (four months) and *Consort* (five months) showing regular increases, while *Constance* (three months), who was not steaming under " economical " conditions, topped the remainder. *Comus* was actually six months out of dock but, after three months, had visited Shanghai for a fortnight, where the sandy river water has a marked known scouring and cleansing effect. It is reasonable to assume that this was equivalent to a bottom scrape and that she was virtually three months out of dock, and her consumptions fit in remarkably closely with the remainder.

Plotting these consumptions on a base of " time out of dock " (Fig. 2) and comparing trial figures, it was deduced that :

After Five Months out of Dock

At speeds of 14–15 knots—

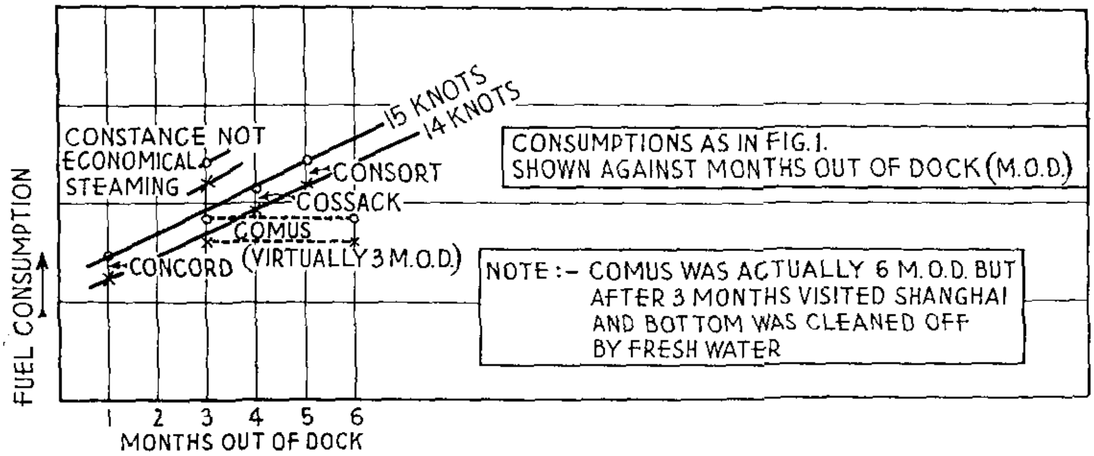

FIG. 2

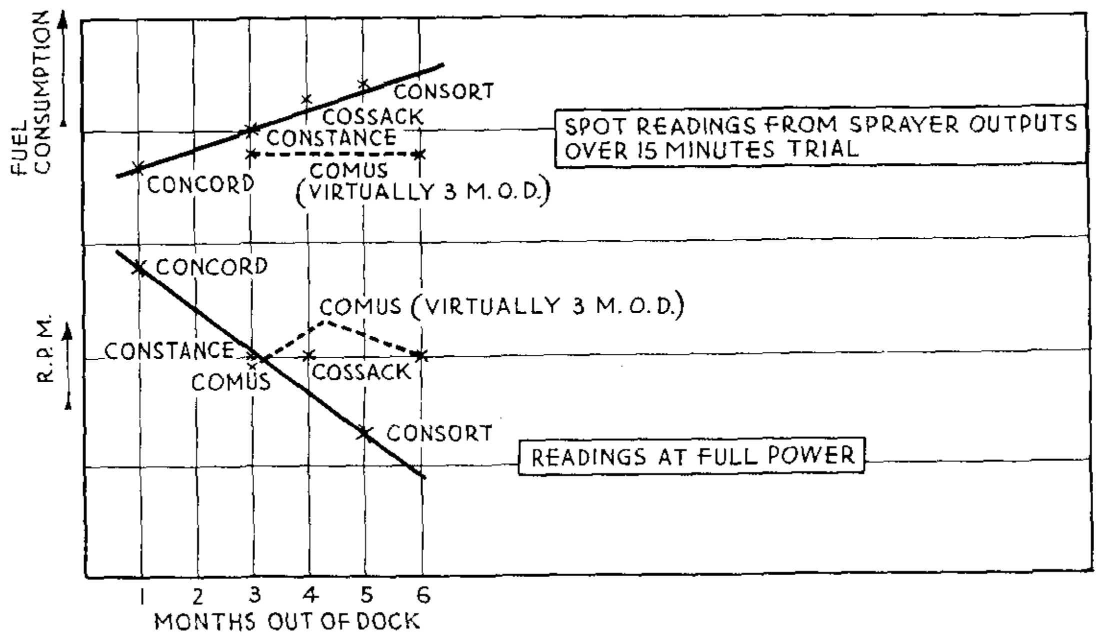

FIG. 3

(*a*) For the same r.p.m., after five months out of dock, the speed was reduced by 1 knot and the consumption increased by about 60%.

(*b*) For the same speed, after five months out of dock, r.p.m. required were increased by 10%, and consumption was increased by about 80%.

35% saving was effected at 14–15 knots by reducing to the minimum auxiliary machinery. (This saving cannot normally be realized when in company.)

At Full Power—

In theory at full power all consumptions should be the same irrespective of time out of dock. It was noted in the above trials that after five months out of dock the r.p.m. at full power dropped 5%, and the fuel consumption was 5% heavier (Fig. 3). The maximum speed dropped by about 1¾ knots.

At speeds approaching that for full power, the consumption to obtain the same speed will, of course, be increased by more than the 5% quoted above.

It should be noted that these results were deduced under ideal conditions, and with no upsetting variables such as bad weather, course alterations, or variation in sea water temperature (82°).

Comparison with other Published Figures

A comparison of these figures with other published figures for ships six months out of dock is shown below :—

	8th D.F.	U.S.N. 310/ft Destroyer*	Cruiser†	U.S.N. 32,000-ton Battleship*
Location ...	Pacific	Atlantic	Mediterranean	California (off)
Increase in Fuel Consumption after 6 months out of dock—				
At 14 knots	90%	90%	60%	28%
At Speeds approaching that for Full Power	10%	25%	60%	25%
Loss of Speed at Full Power	$1\frac{3}{4}$ k.	2 k.	2 k.	1 k.

Resistance to Ships through Water

Some explanation is now necessary to see how the startling increases in consumption shown above are possible. The total resistance to the passage of a normal ship through water is made up of :—

Skin or Frictional Resistance. This clearly varies, among other things, with the state of the bottom.

Wave Resistance, due to the waves created by the ship.

Eddy Resistance, due to the tailing aft of a mass of eddy—confused water caused by change of form (*i.e.*, a square stern or an asdic dome). With proper design it is a minor factor.

Air Resistance, which is seldom large, but by no means negligible.

The power required to overcome skin frictional resistance is a function of $(\text{speed})^{2\cdot83}$.

The power required to overcome wave resistance depends on a great many factors, and is a function of $(\text{speed})^5$ (or higher index) in the 18–28-knot range, decreasing to $(\text{speed})^3$ beyond 30 knots.

For vessels at slow speed, the skin resistance may be as much as 80% of the total resistance. As the speed increases the wave resistance becomes a more and more important factor, and the skin resistance may account for only 40% of the total resistance.

For design purposes, the Admiralty as the result of comparative trials of H.M. ships, clean and dirty over the measured mile, commonly allow an increase of skin resistance of :

$\frac{1}{4}$% per day out of dock in temperate waters,
$\frac{1}{2}$% per day out of dock in tropical waters,

i.e., allow for the skin resistance to increase by 45% after six months out of dock in temperate waters, and 90% in tropical waters.

* Figures deduced from graphs in *The Speed and Power of Ships* by Rear-Admiral D. W. Taylor, U.S.N. (1943).

† Figures deduced from graphs in a paper read by R. W. L. Gawn, Esq., R.C.N.C., before the N.E. Coast Institution of Engineers and Shipbuilders. Vol. LVIII of Transactions 1941–2.

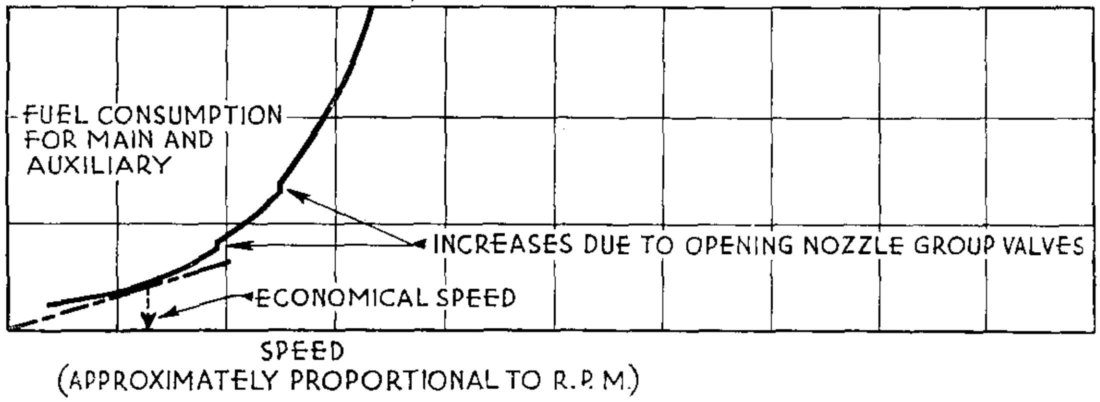

FIG. 4

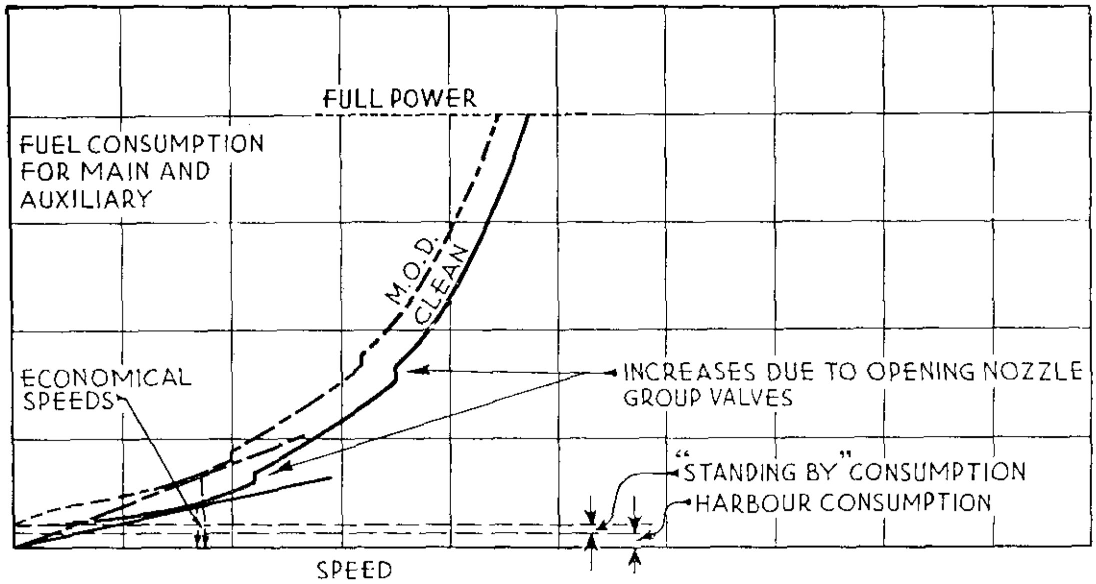

FIG. 5

A 90% increase in skin resistance, which resistance may be 80% of total resistance at low speeds, will therefore cause a proportionately high increase in S.H.P. and hence fuel consumption at such speeds, as is shown for the above destroyers.

The proportionately lesser increase in consumption found near full power is due to the reduced effect of the skin component which component is proportionately smaller in larger ships.

What is a Ship's most Economical Speed ?

The maximum endurance is achieved when the ratio $\frac{\text{Sea Miles Steamed}}{\text{Tons Fuel Carried}}$ is a maximum, *i.e.*, when $\frac{\text{Miles}}{\text{Hour}} \times \frac{\text{Hour}}{\text{Tons Fuel for Main and Auxiliary}}$ is maximum, *i.e.*, when Speed/Consumption for Main and Auxiliary is a maximum, or when $\frac{\text{Consumption for Main and Auxiliary}}{\text{Speed}}$ is a minimum (Fig. 4) which occurs at a speed when the tangent through the origin touches the consumption curve.

The result of a foul bottom is to raise the consumption by a varying amount such as the 90% at 14 knots and 10% at full power found in the 8th Destroyer Flotilla trials above (Fig. 5).

It can be seen that the effect of a foul bottom on " economical speed " may be very small owing to the geometry of the curves, and this was confirmed by various further trials in the 8th Destroyer Flotilla which indicated that the maximum economy was achieved at about 13.5 knots at all states of bottom, with sea water between 75° and 85°, the r.p.m. varying from 122 with a clean bottom to 132 with a foul bottom (six months).

It would be most dangerous to generalize from any of the above figures owing to the numbers of other factors which so greatly affect the most economical speed, and hence endurance, such as :—

(*a*) Weather.

(*b*) Displacement.

(*c*) Sea water temperature, and height of barometer. Variation of vacuum by 1 inch will make about 5% difference in fuel consumption in existing designs of machinery.

It is understood that future steam designs will be based on a lower vacuum and higher sea water temperature than hitherto, and that therefore operations in cold sea water will show as a gain in designed fuel consumption.

(*d*) Usable fuel—is usually taken as 95% of the normal 95% stowage—*i.e.*, 90% of the capacity of the tanks, including diesel.

(*e*) Station keeping and convoy steaming.

(*f*) Steam heating for furnace fuel tanks under Arctic conditions.

(*g*) Use of paravanes.

(*h*) Banking of boilers, warming through stand-by machinery, and running additional action machinery.

Apart from this, the accurate measurement of speed through the water presents great difficulties.

Conclusion

The effect of a foul bottom has, of course, been known to seafarers from time immemorial. In the same way as the keen yachtsman will slip his vessel as often as his pocket permits, so must warships be docked as frequently as economic and operational conditions permit. It can be said that until satisfactory plastic or other bottom compositions are generally in use, daily fuel bills may be increased over those for clean bottom conditions by half as much again at the end of a six months period of steaming at peace-time speeds; at faster wartime speeds the increase will be less.